

XVI. *Directions for making the best Composition for the Metals of reflecting Telescopes; together with a Description of the Process for grinding, polishing, and giving the great Speculum the true parabolic Curve. By Mr. John Mudge; communicated by Alexander Aubert, Esq. F. R. S.*

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AS the method of casting, grinding, and polishing the specula of reflecting telescopes, by Mess. MOLYNEUX and HADLEY, which is published in Dr. SMITH's Optics, is what the workmen have generally followed, and is consequently well known to them; I shall in the following account avoid a repetition of the general directions there given, and only remark upon such parts of that process which I think are essentially defective, and supply them by a method of my own, which, from long and repeated trials, I have found completely to answer the purpose. After, therefore, referring to the above account for the manner of making the gages, patterns, the method of casting, as well as a great many other particulars, I will begin with

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*The best composition for the specula of reflecting telescopes.*

The perfection of the metal of which the speculum should be made consists in its hardness, whiteness, and compactness; for upon these properties the reflective powers and durability of the speculum depend. And first of the hardness and whiteness of the metal. There are various compositions recommended in SMITH'S Optics, all which have however their several defects. Three parts copper and one part and one-fourth of tin will make, he says, a very hard white metal; but it is liable to be porous. This, however, is an imperfection which I shall presently shew the method of preventing; but the permanent fault of it, and which I have myself experienced, is, that it is not hard enough. The speculum of a reflecting telescope ought to have the utmost possible hardness, compatible with its being operated upon by the tool.

It is to be observed, that ever so small a quantity of tin added to melted copper destroys its perfect malleability, and at the same time produces a metal whiter and harder than copper. As the quantity of tin is increased, suppose to a fifth or fourth part, the metal becomes whiter, still harder, and consequently more friable. If the quantity of tin be further increased to a third of the

whole composition, it will then have its utmost whiteness; but will be rendered at the same time so exceedingly hard and brittle, that the finest washed emery upon lead or brass will not cut it without breaking up its surface; and the common blue stones used in grinding the speculum, will not touch it. Mr. JACKSON (some time since dead) a mathematical-instrument-maker, and a most excellent workman, told me, that the tin was increased to the above proportion in his metals; but that they were so exceedingly hard, that it cost him an infinite deal of pains, and a journey of two hundred miles, to find out a stone of sufficient hardness to cut it, and whose texture at the same time was fine enough not to injure its surface. I have seen several of his finished metals; they were indeed perfectly hard and white; but the kind of stone with which he ground them he kept a secret.

After many experiments with various proportions of tin and copper, by gradually increasing the former, I at last found that fourteen ounces and an half of grain-tin to two pounds of good Swedish copper, made a beautiful white and very hard metal; so hard indeed, that the stones would but barely cut it, and washed emery on brass or tin but just grind the surface without breaking it up; whereas the proportion of tin being increased by the addition of only another half ounce, the former inconvenience

venience immediately took place. This therefore is the *maximum* in point of hardness.

Thus much of the two first considerations, the hardness and whiteness of the metal; the next, and indeed the most essential, property is its compactness, or its being without pores.

This composition (though complete in the former respects) was, as well as Dr. SMITH's, subject every now and then to be porous; sometimes, indeed, I succeeded in casting a single metal, or perhaps two or three, without this imperfection; at other times, and most frequently indeed, they were attended with this defect, without my being at all able to form a probable conjecture at the cause of my success or disappointment. The pores were so very small that they were not discoverable when the metal had received a good face and figure upon the bones, nor till the last and highest polish had been given; and then it frequently appeared as if dusted over with millions of microscopic pores, which were exceedingly prejudicial in two respects; for first, they became in time a lodgment for a moisture which tarnished the surface; and secondly, on polishing the speculum, the putty necessarily rounded off the edges of the pores, so as to spoil a great part of the metal, by the loss of as much light and

sharpness in the image as there were defective points of reflection in the metal.

Besides the trouble of a great number of experiments, in order to get rid of this mischief, and to ascertain the cause to which it was owing, there was this additional inconvenience attending it, *viz.* that the fault was not discovered, as was observed before, till a great deal of trouble had been taken in grinding and even polishing the metal, the whole of which was rendered useless by the mortifying discovery of this defect.

I was extricated at last from this difficulty, and in some measure by accident. Having one day made a great number of experiments, and having melted down all the good copper I had or could procure; though puzzled and fatigued, yet not caring to give it up, I recollected that I had some metal which was reserved out of curiosity, and was a part of one the bells of St. Andrew's which had been re-cast. Expecting, however, very little from this gross and uncertain composition, I was nevertheless determined to see what could be made of it by enriching the composition with a little fresh tin. Accordingly casting a metal with it, it turned out perfectly free from pores, and in every respect as fine a metal as ever I saw.

I could not at first conceive to what this success was owing; but at last I hit upon the real cause of that defect,

which had given me so much embarrassment and trouble during a course of near a hundred experiments, and in consequence thereof fell upon a method which ever after prevented it.

I had hitherto always melted the copper first, and when it was sufficiently fused, I used to add the proportional quantity of tin; and as soon as the two were mixed, and the scoria taken off, the metal was poured into the moulds. I began to consider that putty was calcined tin, and strongly suspected, that the excessive heat which the copper necessarily undergoes before fusion, was sufficient to reduce part of the tin to this state of calcination, which therefore might fly off from the composition in the form of putty, at the time the metal was poured into the flasks.

Upon this idea, after I had furnished myself with some more Swedish copper and grain-tin (both which I had always before used) I melted the copper, and having added the tin as usual to it, cast the whole into an ingot: this was, as I expected, porous. I then melted it again, and as in this mixed state it did not acquire half the heat which was before necessary to melt the copper alone, so it was not sufficient to calcine the tin; the speculum was then perfectly close, and free from this fault; nor did I ever after, in a single instance, meet with the above mentioned imperfection.

All that is necessary, therefore, to be done to procure a metal which shall be white, as hard as it can be wrought, and perfectly compact, is to melt two pounds of Swedish copper, and when so melted, to add fourteen ounces and a half of grain-tin to it; then, having taken off the scoria, to cast it into an ingot. This metal must be a second time melted to cast the speculum; but as it will fuse in this compound state with a small heat, and therefore will not calcine the tin into putty, it should be poured off as soon as it is melted, giving it no more heat than is absolutely necessary. It is to be observed, however, that the same metal, by frequent melting, loses something of its hardness and whiteness: when this is the case, it becomes necessary to enrich the metal by the addition of a little tin, perhaps in the proportion of half an ounce to a pound. And indeed when the metal is first made, if instead of adding the fourteen ounces and a half of tin to the two pounds of melted copper, about one ounce of the tin were to be reserved and added to it in the succeeding melting, before it is cast off into the moulds, the composition would be the more beautiful, and the grain of it much finer: this I know by experience to be the case.

The best method for giving the melted metal a good surface is this: the moment before it is poured off, throw into the crucible a spoonful of charcoal-dust; imme-

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diately after which the metal must be stirred with a wooden spatula, and poured into the moulds.

I wish I may not be considered as tedious in the above detail; but as this business caused me a great deal of trouble, I was willing to give some account of the means by which I was freed from this difficulty ever after. Perhaps, indeed, the whole of this process may be unnecessary, as many years since, I communicated this composition, and I believe at the same time the method of preventing the pores, to the late Mr. PETER COLLISON, a member of the Royal Society; and likewise two or three years since, at the desire of my brother, to Mr. MICHELL. Although it be possible, therefore, that this method is generally known, yet, as I have frequently of late seen specula with this defect, and observed metals of some of Mr. SHORT's telescopes which are not quite so perfect as could be wished (though they are all exquisitely figured) I was willing by this publication wholly to remove any future embarrassment of this sort, and to furnish workmen with an excellent composition for their metals. And would the Royal Society be pleased to honour the process with a place in their records, I know of no other method so proper to give this, as well as the following information, a general notoriety.

The metal being cast, there will be no occasion for the complicated apparatus directed by Dr. SMITH, for grinding

grinding and polishing it. Four tools are all that are necessary, *viz.* the rough grinder to work off the rough face of the metal; a brass convex grinder, on which the metal is to receive its spherical figure; a bed of hones which is to perfect that figure, and to give the metal a fine smooth face; and a concave tool or bruiser, with which both the brass grinder, and the hones are to be formed. A polisher may be considered as an additional tool; but as the brass grinder is used for this purpose, and its pitchy surface is expeditiously, and without difficulty formed by the bruiser, the apparatus is therefore not enlarged.

*Of rough grinding the speculum.*

The tool by which the rough surface of the metal is rendered smooth and fit for the hones, is best made of lead, stiffened with about a fifth or sixth part of tin. This tool should be at least a third more in diameter than the metal which is to be ground; and for one of any size, not less than an inch thick. It may be cemented upon a block of wood, in order to raise it higher from the bench.

This leaden tool being cast, it must be fixed in the lathe, and turned as true as it is possible, by the gage, to the figure of the intended speculum, making a hole or pit in  
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the middle, as a lodgment for the emery, of about an inch diameter for a metal of four inches: when this is done, deep grooves must be cut across its surface with a graver, in the manner represented in fig. 1. These grooves will serve to lodge the emery, and by their means the tool will cut a great deal faster. There is no occasion to fear any alteration in the convexity of this tool by working the metal upon it, for the emery will bed itself in the lead, and so far arm the surface of it, that it will preserve its figure and cut the metal very fast. Any kind of low handle, fixed on the back of the metal with soft cement, will be sufficient; but it should cover two-thirds of its back to prevent its bending. This way of working will cut the metal faster, and with more truth, than the method described by Dr. SMITH; for should the surface and rough parts be attempted to be ground off by a common grind-stone by hand, though you did it as near the gage as possible, yet the metal would be so much out of truth when applied to the succeeding tool, that no time would be saved by it. I used to employ a common labourer for this purpose, who soon acquired such a dexterity at working upon this tool, that in two hours time he would give a metal of four inches diameter so good a face and figure as even to fit it for the hones. When all the sand-holes and irregularities on the face of the metal are ground off, and the whole surface

is smooth and regularly figured, the speculum is then ready for the brass grinder, and must be laid aside for the present.

*The manner of forming the brass-grinding tool.*

The following is the method I have always pursued. Procure a round stout piece of Hamburgh brass, at most a sixth part larger than the metal to be polished; and let it be well hammered into a degree of convexity (by the assistance of the gage) suitable to the intended speculum. Having done this, scrape and clean the concave side so thoroughly that it may be well tinned all over; then cast upon it, after it has been pressed a proper depth into the sand, the former composition of tin and lead, in such quantity, that it may (for a speculum of four inches diameter) be at least an inch and an half thick, and with a base considerably broader than the top, in order that it may stand firmly upon the bench in the manner hereafter to be described. This being done, it must be fixed and turned in the lathe with great care, and of such a convexity as exactly to suit the concave gage, which we suppose already made. It will be necessary to be more careful in forming this than the former tool, and especially that no rings be left from the turning;

nor will the succeeding hone tool require so much exactness, as any defects in turning, will, by a method hereafter mentioned, be easily remedied; but any inequality or want of truth in the brass tool will occasion a great deal of trouble before it can be ground out by the emery. This tool must have a hole (somewhat less than that in the metal to be worked upon it) in the middle, quite through to the bottom. When this tool is finished off in the lathe, its diameter should be one-eighth wider than the metal.

*How to form the bed of hones, or the third tool.*

Having chosen the kind of hones, and the best too, of the sort recommended in SMITH'S Optics; they should be cemented in small pieces (in a kind of pavement agreeably to his directions) upon a thick round piece of marble, or metal made of lead and tin like the former composition (which is what I have always used) in such a manner, that the lines between the stones may run straight from one side to the other; so that, placing the teeth of a fine saw in each of these divisions, they may be cleared from one end to the other of the cement which rises between the stones. This bed of hones should be at least a fourth part larger than the metal which is to be ground upon it. The surface of the

metal upon which the hone pavement is to be cemented may or may not, as you please, be turned of a convexity suitable to the gage, though I have never taken that trouble. As soon as the hones are cemented down, and the joints cleared by the saw, this tool must be fixed in the lathe, and turned as exactly true to the gage as possible; which done, it must be laid aside for the present. The next tool to be made is the bruifer.

*The manner of forming the bruifer, the fourth and last tool.*

This tool should be likewise made of thick stout brass like the former, perfectly sound, about a quarter of an inch thick, and hammered as near to the gage as possible. It should be then scraped, cleaned, and tinned on the convex side, as the former tool was on the concave, and the same thickness of lead and tin cast upon it. The general shape of this should differ from the former; for as that increased in diameter at the bottom for the sake of standing firmly, so this should be only as broad at bottom as at top, as it is to be used occasionally in both those positions. When this tool is fixed in the lathe, and turned off concave to the convex gage with great truth  
likewise,

likewise, its diameter ought to be the middle size between the hones and the polisher.

Having with the lathe roughly formed the convex brass grinder, the bed of hones, and the concave bruifers, the convex and concave brass tools and the metal must be wrought alternately and reciprocally upon each other with fine emery and water, so as to keep them as nearly to the same figure as possible, in order to which some washed emery must be procured. This is best done by putting it into a phial, which must be half filled with water and well shaken up, so that, as it subsides, the coarsest may fall to the bottom first, and the finest remain at the top: and whenever fresh emery is laid on the tools, the best method (which we should also observe with the putty in polishing) will be, to shake gently the bottle, and pour out a small quantity of the turbid mixture.

*Of grinding the speculum, the brass tool, and the bruifer, together.*

All the tools being ready, upon a firm post in the middle of a room, you are to begin to grind the brass convex tool with the bruifer upon it, working the latter cross-ways, with strokes sometimes across its diameter, at others a little to the right and left, and always so short that the  
bruifers

bruifers may not pass above half an inch within the surface of the brass tool either way, shifting the bruifer round its axis every half dozen strokes or thereabout. You must likewise, every now and then, shift your own position, by walking round, and working at different sides of the brass tool; at times the strokes should be carried round and round, but not much over the tool: in short, they must be directed in such a way, and the whole grinding conducted in such a manner and with such equability, that every part of both tools may wear equally. This habit of grinding, as well as the future one of polishing, will be soon acquired. When you have wrought in this manner about a quarter of an hour with the bruifer upon the tool, it will be then necessary to change them, and, placing the bruifer upon its bottom, to work the convex tool upon that in the same manner.

When by working in this equable manner, alternately with the bruifer and tool, and occasionally adding fresh emery, you have nearly got out all the vestiges of the turning tool, and brought them both nearly to a figure, it will be then time to give the same form to the metal. This must be done by now and then grinding it upon the brass tool with the same kind of emery, taking care however, by working the two former tools frequently together, to keep all three exactly in the same curve.

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The best kind of handle for the metal is made of lead, a little more than double its thickness, and somewhat less in diameter, of about three pounds weight, with a hole in the middle (for reasons to be shewn hereafter) a little larger than that in the metal: this handle should be cemented on with pitch. The upper edge of this weight must be rounded off, that the fingers may not be hurt; and a groove, about the bigness of the little finger, be turned round just below it, for the more conveniently holding and taking the metal off the tools.

*The manner of figuring the metal upon the hones.*

When the bruiser, brass tool, and metal, are all brought to the same figure, and have all a true good surface, the next part of the process is to give a correct spherical figure and a fine face to the metal, upon the hones. It will be necessary to premise, however, that the hones should be placed in a vessel of water, with which they should be quite covered for at least an hour before they are used, otherwise they will be perpetually altering their figure when the metal comes to be ground upon them. The same precaution is also necessary, if you are called off from the work while you are grinding

grinding the metal, for if they be suffered to grow dry, the same inconvenience will arise.

In order to give a proper figure to the hones, and exactly suitable to that of the brass tool, brouser, and metal, when the hones are fixed down to the block, some common flour emery (unwashed) with a good deal of water must be put upon them, and the brouser being placed upon the hones and rubbed thereon with a few strokes and a light hand, the inequalities of the stone will be quickly worn off; but as a great deal of mud will be suddenly generated, it must be washed off every quarter of a minute with a great deal of water. By a repetition of this, two or three times, the hones (being of a very soft and friable substance) will be cut down to the figure, without wearing or altering the brouser at all. Though this business may be quickly done, and can be continued but for a few strokes at a time, I need not say that it is necessary that those strokes be carried in the same direction, and with the same care, which was observed in grinding the former tools together.

As soon as the hones have received the general figure of the brouser, and all the turning strokes are worn out from them, the emery must be carefully washed off; in order to which, it will be necessary to clear it from the joints with a brush under a stream of water. The brouser

and metal must be likewise cleared in the same manner, and with equal care, from any lurking particles of emery.

The hones being fixed down to the block, you now begin to work the bruifer upon them with very cautious, regular, short strokes, forward and backward, to the right and left, turning the axis of the bruifer in the hand while you move round the hones, by shifting your position, and walking round the block. Indeed the whole now depends upon a knack in working, which should be conducted nearly in the following manner. Having placed the bruifer on the centre of the hones, slide it in an equable manner forward and backward, with a stroke or two directly across the diameter, a little on one side, and so on the other; then shifting your position an eighth part round the block, and having turned the bruifer in your hand about as much, give it a stroke or two round and round, but not far over the edges of the hones, and then repeat the cross strokes as before: those round strokes (which ought not to be above two or three at most) are given every time you shift your own position and that of the metals, previous to the cross ones, in order to take out any stripes either in the hones or bruifer, which may be supposed to be occasioned, by the straight cross strokes. During the time of working, no mud must be suffered to collect upon the hones, so as to

destroy the perfect contact between the two tools; and therefore they must every now and then be washed clean by throwing some water upon them. When by working in this manner all the emery strokes are ground off from the bruiser, and it has acquired a good figure and clean surface, you may then begin with the metal upon the hones, in the same cautious manner, washing off the mud as fast as it collects, though that will be much less now than when the bruiser was ground upon them. Every now and then, however, the bruiser must be rubbed gently and lightly upon the hones, which will as it were, by sharpening them and preventing too great smoothness, occasion them to cut the metal much faster.

When, after having some time cautiously wrought in the manner before described, the hone-pavement has uniformly taken out all the emery strokes, and given a fine face and true figure to the metal, which will be pretty well known by the great equality there is in the feel while you are working, and by which an experienced workman will form a pretty certain judgment; having proceeded thus far, I say, you may then try your metal, and judge of its figure by this more certain manner.

Wash the hone pavement quite clean; then put the metal upon the center of it, and give two or three light strokes

strokes round and round only, not carrying, however, the edges of the metal much over the hones; this will take out the order of straight strokes: then having again washed the hones, and placed the speculum upon their center, with gentle pressure, slide it towards you till its edge be brought a little over that of the hones, then carry it quite across the diameter as far the other side, and having given the metal a light stroke or two in this direction, take it off the tool. The metal being wiped quite dry, place it upon a table at a little distance from a window; stand yourself as near the window, at some distance from the metal, and looking obliquely on its surface, turn it round its axis, and you will see at every half turn the grain given by the last cross strokes flash upon your eye at once over the whole face of the metal. This is as certain a proof of a true spherical figure as the operose and difficult method described in Dr. SMITH's Optics; for as there is nothing soft or elastic, either in the metal or in the hones, this glare is a certain proof of a perfect contact in every part of the two surfaces; which there could not be if the spheres were not both perfect and precisely the same.

Indeed there is one accidental circumstance which necessarily affords its aid in this and every business of the like sort; and that is, that a concave and convex surface

ground together, though ever so irregular at first, will (if the working be uniform and proper; consisting, especially at last, of cross strokes in every possible direction across the diameter) be formed into portions of true and equal spheres; had it not been for this lucky necessity, it would have been impossible to have produced that correctness which is essential in the speculum of a good reflecting telescope by any mechanic contrivance whatever. For when it is considered, that the errors in reflection are four times as great as in refraction, and that the least defect in figure is magnified by the powers of the instrument, any thing short of perfection in the figure of the speculum would be evidently perceived by a want of distinctness in the performance.

I must not, however, quit this article without observing, that I all along suppose, both in forming the tools and at last figuring the metal (and indeed the same must be observed in the future process of polishing) that no kind of pressure is used that may endanger the bending or irregularly grinding them; they should therefore be held with a light hand, and loosely between the fingers, and the motion given should be in a horizontal direction, with no more pressure than their own dead weight:

Having now finished the metal on the hones, and rendered it both in point of figure and surface fit for the  
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last and most essential process, *viz.* that of polishing, I will describe it in the best manner I can; though many little circumstances which will be unavoidably omitted (and which at the same time are frequently essential to the success of a mechanic process) can only be supplied by actual experience.

The polishing the speculum is the most difficult and essential part of the whole process; for every experienced workman knows, to his vexation, that the most trifling error here will be sufficient to spoil the figure of his metal, and render all his preceding caution useless. I have, however, discovered a method which I shall explain, not only of giving the metal a parabolic figure, but also of recovering it when it happens to be injured; both to be effected in the act of polishing, and the former as certainly as the spherical figure is given upon the hones. Indeed, if we consider rightly, polishing will be perceived to be but a kind of grinding with a finer order of strokes, and with a powder infinitely finer than was before used in what is commonly called the grinding. But before I describe this method, which was the result of many years experience, I will take the liberty of making some few strictures on that of Mess. HADLEY and MOLYNEUX, which is followed by the generality of workmen.

First

First, then, the tool itself used by them for polishing the metal, is formed with infinite difficulty. The first described polisher is directed to be made by covering the tool with scarfenet, which is to be saturated with a solution of pitch in spirit of wine, by successive applications of it with a brush, till it is covered, and by the evaporation of the spirit of wine filled with this extract of pitch; the surface is then to be worked down and finished with the bruifer. This is all very easy in imagination; but whoever has used this method (which I have myself unsuccessfully several times) must have found it attended with infinite labour, and at last the business done in a very unsatisfactory manner; for the pitch by this process will be deprived of an essential part of its composition. The spirit of wine dissolves none but the resinous parts of its substance, which is hard and untractable; and if you use soap or spirit of wine to soften or dissolve it, it will equally affect the whole surface, the lower as well as higher parts of it. And suppose that with infinite labour with the bruifer, it is at last reduced to a fine uniform surface, it is nevertheless too hard ever to give a good polish with that lustre which is always seen in Mr. SHORT's, and indeed all other good metals. Nor will it give a good spherical figure; for a perfect sphere is formed, as I observed before, by that intimate accommodation

dation arising from the wear and yielding of both tool and metal; whereas in this method, there is such a stubbornness in the polisher, that the figure of the metal, good or bad, must depend upon the truth of the former, which is very seldom perfect.

If the polisher be made in the second manner proposed, by straining the pitch through an outer covering, which is afterwards to be stripped off, the superficies of pitch and sartenet is so very thin, that the putty, working into them, forms a surface hard and untractable, so that it is impossible to give the speculum a fine polish. Accordingly all those metals which are wrought that way have an order of scratches instead of polish, discovering itself by a greyish visible surface. Besides, supposing this tool perfectly finished, and answering its purpose ever so well, it is impossible it can produce in the speculum any other than a spherical figure; and indeed nothing else is expected from this method, as very evidently appears by the experiment recommended to ascertain the truth of the figure. You are directed to place a small luminous object in the center of the sphere of which the metal is a segment; and then having adjusted an eye-glass at the distance of its own focal length from the object, and so situated that the image of the object formed by the speculum may be visible to the eye, you are to judge of the

perfect figure of the metal by the sharpness and distinctness with which the image appears. From hence it is very evident, that as the object and image are both distant from the metal by exactly its radius, nothing but a true spherical figure of the speculum can produce a sharp distinct image; and that the image could not be distinct if the figure of the speculum were parabolic. Consequently, if the same speculum used in a telescope were to receive parallel rays, there would necessarily be a considerable aberration produced, and a consequent imperfection in the image. Accordingly, there never was a good telescope made in this manner; for if the number of degrees, or the portion of the sphere of which the great metal is a part, were as considerable as it ought to be, or as great as Mr. SHORT allowed in his metal, the instrument would bear but a very low charge, unless a great part of the circumference of the metal were cut off by an aperture, and the ill effects of the aberration by that means in some measure prevented.

If ever a finished metal turned out without this defect, and has been found perfectly sharp and distinct, it must have been owing to an accidental parabolic tendency, no ways the natural result of the process, and therefore quite unexpected, and most probably unknown, to the workman.

Without

Without enlarging, therefore, on the difficulty of the above process, and the impossibility of giving the speculum the correctness and the kind of figure essentially necessary to a good telescope, I will describe (by way of introduction to the succeeding directions) the steps by which I was led to a certain and easy method of giving a proper and correct parabolic figure to the metal, even though it came off imperfect from the hones, and an exquisite polish at the same time.

Having made many efforts in the former method, which by no means pleased me for the reasons above-mentioned; and having observed, from some of Mr. SHORT'S telescopes which fell into my hands, that the high lustre of the polish could never have been produced in the manner above described, but by some softer and more tender substance; and at the same time recollecting, that Sir ISAAC NEWTON had given an account in his Optics of his having finished some metals, and considerably mended the object glass of a refractor, by working both upon a tool whose surface had been covered with common pitch about the thickness of a groat; reflecting, I say, upon these matters (coarse and uncertain as this method appeared at first sight) I was determined to try whether I could not get rid of my embarrassment, by a mode of operation somewhat similar. Accordingly, shortening

Dr. SMITH's process, I made a set of tools in the manner before described, except that I was obliged to make some subsequent alteration in the polisher which I shall presently describe. Having given a good spherical figure to the brass tool and the bruiser, and likewise to the metal upon the hones, and made the brass convex tool so hot as just not to hurt the finger, I tied a lump of common pitch (which should be neither too hard nor too soft) in a rag, and holding it in a pair of tongs over a still fire where there was no rising dust, till it was ready to strain through the linen, I caused it to drop upon the several parts of the convex tool, till I supposed it would cover the whole surface about double the thickness of a shilling; then spreading the pitch as equally as I could, I suffered the polisher (by which name I shall for the future call this tool) to grow quite cold. I then warmed the bruiser so hot as almost to burn my fingers, and having fixed it to the bench with its face upwards, I suddenly placed the polisher upon it, and quickly slid it off; by this means rendering the surface of the pitch more equal. The pitch is then to be wiped off from the bruiser with a little tow; and by touching the surface with a tallow candle, and wiping it a second time, it will be then perfectly clean and fit for a second process of the same sort, which must again be performed as quickly as possible; and

and this is ordinarily sufficient to give a general figure to the surface of the pitch. The bruiser and polisher are then suffered to grow perfectly cold, when the pitch, considering what has been taken off, will be about the thickness of a shilling.

It is however here necessary to observe, that the pitch should be neither very hard and resinous, nor too soft; if the former, it will be so untractable as not to work kindly; and if too soft, it will in working alter its figure faster than the metal, and too readily fit itself to the irregularity of its figure, if it have any. When both tools were perfectly cold, I gave the polisher a gentle warmth, and then fixed the bruiser to the block with its face upwards; and (having with a large camel's-hair brush spread over the face of the polisher a little water and soap, to prevent sticking) with short, straight, and round strokes I worked it upon the bruiser, every now and then adding a little more water and soap, till the pitch upon the polisher had a fine surface, and the true form of the bruiser; and this I continued to do till they both grew perfectly cold together: in this manner the polisher was perfectly formed in about a quarter of an hour. But here a difficulty arose: when I begun to polish the metal, I found that the edge of the hole in the metal collected the pitch towards the middle of the polisher; and

though in this method of working I could give an exquisite polish, as the putty lodged itself in the pitch exceedingly well, yet the figure of the metal was injured in the middle, nor did indeed the work go on with that equability which is the inseparable attendant on a good figure. In order to obviate this difficulty, I cast some metals with a continued face, the holes not going quite through, within perhaps the thickness of a six-pence. I finished two or three metals of this sort, and the work promised and went on very well; but when I came to open the holes, which I did with the utmost caution, I found the metals short of perfection; which I attributed to an alteration of the figure from the removal of even that small portion of metal after the speculum had been finished. This I do suppose was in some measure the reason why I spoiled a very distinct and perfect two-foot metal, which bore a charge of two hundred times, only by opening the sharp part of the edge of the hole, because I thought it bounded the field: so essentially necessary is an exquisite correctness of figure in the speculum of a perfect reflector.

This experiment not succeeding, instead of casting the metal without a hole, I made one quite through the middle of the polisher, a little less than that in the speculum. This perfectly answered the purpose; no more  
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inconvenience arose from the gathering of the pitch (for it had now no greater tendency to collect at the center than the sides) and I finished several metals successively, excellent both in point of figure and polish; one of those of two inches diameter and 7,5 focal length, bore a charge of sixty times and upwards, which when mounted in a telescope I gave to my brother. This telescope underwent Mr. SHORT's examination, who was pleased to remark only, that he thought he had made one more distinct.

I must observe, that in this method of working the polishing goes on in an agreeable, uniform, and smooth manner; and that the small degree of yielding in the pitch (which is actually not more than the wearing of the metal) produces that mutual accommodation of surfaces so necessary to a true figure. In the beginning of the polish, and indeed for some time during the progress of it (always remembering now and then to move the metal round its axis) I worked round and round, not far from and always equally distant from the center, except that every time, previous to the shifting the metal on its axis, I used a cross stroke or two; and when the polish was nearly completed, I mostly used cross strokes, giving a round stroke or two likewise every time I turned the metal on its axis. I observed in this method of working, that the metal always polished fastest in the middle; inasmuch,

infomuch, that half or two-thirds of it would be completely polished when the circumference of it was scarcely touched by the tool. Observing this in some of the first metals, and not considering that this way of polishing was in fact a species of grinding, and as perfect as that upon the hones, I went on reluctantly with the work, almost despairing of being able to produce a good figure. However, I always found myself agreeably deceived; for when the polish was extended to the edge, or within the tenth of an inch of it, I almost constantly found the figure good, and the performance of the metal very distinct. But this same circumstance of apparent defect in the metals, was in fact that to which their perfection was owing; for they all, contrary to my expectation, turned out parabolic. However I did not for a great while know any certain way of giving that degree of parabolic tendency which was just necessary, and which will be described hereafter. It was a long time before I got rid of my prejudice against this apparent imperfection in the process, or could reconcile myself to the irregular manner in which the polish proceeded; for I looked upon it as a certain source of error, and notwithstanding I saw it eventually succeed, yet whenever I chanced to find that a metal, when first applied to the polisher, took the polish equally all over,  
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and consequently the whole business did not take up above ten minutes; under those circumstances, I say, I always used to please myself with the expectation of a correct figure, at least as much so as the metal had received from the hones, where the surface was but just and equally taken off by the putty; but in this I constantly found myself deceived, and the metal turned out good for nothing. In short, at this time, though I speculatively knew that a parabolic figure was necessary to a perfect image, I yet considered it as of little practical consequence.

From the foregoing experiments, and a number of succeeding trials, I at length discovered a certain way of giving a correct parabolic figure, and an exquisite polish at the same time. This, which I have strong reasons to believe was Mr. SHORT's method, I will now describe in as few words as I can.

*How to polish the Speculum.*

It is first necessary to observe, that, in order to avoid the detrimental intrusions of any particles of emery, it would not be right to polish in the same room where the metal and tools were ground, nor in the same cloaths which were worn in the former process; at least it would

be necessary to keep the bench quite wet, to prevent any dust from rising.

Having then made the polisher by coating the brass convex tool equally with pitch, which we suppose smoothed and finished with the brass tool in the manner before described, and which is a very easy process, the whole operation is begun and finished in the following manner.

The leaden weight or handle upon the back of the metal should be divided into eight parts, by so many deep strokes of a graver upon the upper surface of the lead, marking each stroke with the numbers 1, 2, 3, 4, and so on, that the turns of the metal in the hand may be known to be uniform and regular.

To prevent any mischief from coarse particles of putty, I always wash it immediately before using. In order to this, put about half an ounce of putty into an ounce phial, and fill it two-thirds with water; then having shaken the whole, let the putty subside, and stop the bottle with a cork.

In a tea-cup with a little water, there should be a full-sized camel's-hair brush, and a piece of dry clean soap in a galley-pot: a soft piece of sponge will also be necessary. These, as well as the metal bruiser and polisher, should be constantly covered from dust.

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The polisher being fixed down, and the camel's-hair brush, being first wetted and rubbed a little over the soap, let every part of the tool be brushed over therewith; then work the bruiser with short, straight, and round strokes, lightly upon the tool, and continue to do so, now and then turning it, till the polisher have a good face, and be fit for the metal. Then having shaken up the putty in the phial, and touched the polisher in five or six places with the cork wetted with that and the water, place the bruiser upon the tool, and give a few strokes upon the putty to rub down any gritty particles; after which, having removed it, work the metal lightly upon the polisher round and round, carrying the edges of the speculum, however, not quite half an inch over the edge of the tool, and now and then with a cross stroke.

The first putty, and indeed all the succeeding applications of it, should be wrought with a considerable while; for if time be not given for the putty to bed itself in the pitch, and any quantity of it lie loose upon the polisher, it will accumulate into knobs, which will injure the figure of the metal: and therefore as often as ever such knobs arise, they must be carefully scraped off with the point of a penknife, and the loose stuff taken away with the brush. After the putty is well wrought into the pitch, some more may be added in the same manner, but

never much at a time, and always remembering to work upon it first with the bruiser, for fear any gritty particles may find their way upon the polisher. If the bruiser be apt to stick, and do not slide smoothly upon the pitch, the surface of either tool may be occasionally brushed over with the soap and water, but it must be remembered that the wet brush must be but lightly rubbed upon the soap.

In the beginning of this process little effect is produced, and the metal does not seem to polish fast, in some measure owing to its taking the polish in the middle, and perhaps because neither that nor the bruiser move evenly upon the polisher: but a little perseverance will bring the whole into a good temper of working; and, when the pitch is well defended by the coating of the putty, the process will advance apace, and the former acquiring possibly some little warmth, the metal moves more agreeably over it, with an uniform and regular friction. All this while the metal must have no more pressure than that which it derives from its own weight and that of the handle; and the polisher must never be suffered to grow dry, but, as often as it has any tendency to do so, the edges of it must be moistened with the hair-pencil; and now and then, even when fresh putty is not laid on, the surface of the polisher should be touched with the brush to keep it moist.

When the polish of the metal nearly reaches the edge (for it always, as I said before, begins in the middle) you must alter your method of working; for now the round strokes must be gradually altered for the short and straight ones. Supposing then you are just beginning to alter them; after having put on fresh putty, and gently rubbed it with two or three strokes of the bruiser, you place the metal on the tool, and after a stroke or two round and round, give it a few forward and backward, and from side to side, but with the edges very little over the tool; then having turned the metal one-eighth round in your hand, and having moved yourself as much round the block (which must be remembered throughout the whole process) you go on again with a stroke or two round, to lead you only to the cross strokes, which are now to be principally used, and with more boldness. After this has been done some time, the metal will begin to move stiffly as the friction now increases, and the speculum polishes very beautifully and fast; and the whole surface of the polishing tool will be equally covered over with a fine metallic bronze. The tool even now must not be suffered to become dry; a single round stroke in each of your stations and turnings of the metal will be sufficient, and the rest must all be cross ones, for we are completing a circular figure. You must now be very

diligent, for the polisher drying, and the friction increasing very fast, the business of the spherical figure is nearly at an end. As the metal wears much, its surface must be now and then cleaned, with a piece of shammy leather, from the black stuff which collects upon it; and the polisher likewise from the same matter, with a soft piece of wet sponge. You will now be able to judge of the perfect spherical figure of the metal and tool, when there is a perfect correspondence between the surfaces, by the fine equable feel there is in working, which is totally free from all jerks and inequalities. Having proceeded thus far, you may put the last finishing to this figure of the metal by bold cross strokes, only three or four in the directions of each of the eight diameters, turning the metal at the same time: this must be done quickly, for it ought, in this part of the process particularly, to be remembered, that, if you permit the tool to grow quite dry, you will never be able, with all your force, to separate that and the metal, without destroying the polisher by heat.

The metal has now a beautiful polish and a true spherical figure, but will by no means make a sharp distinct image in the telescope: for the speculum (if it be tried in the manner hereafter recommended) will not be found to make parallel rays converge without great aberration;

aberration; indeed the deviation will be so great, as to be very sensibly perceived by a great indistinctness in the image.

*How to give the parabolic figure to the metal.*

In order then to give the speculum the last and finishing figure, which is done by a few strokes, it must be particularly remarked, that by working the metal round and round, the sphere of the polisher by this means growing less, it wears fastest in the middle: and as a segment of a sphere may become parabolic, by opening the extremes gradually from within outwards, so it may be equally well done by increasing the curvature in the middle, in a certain ratio, from without inwards.

Supposing then the metal to be now truly spherical, stop the hole in the polisher, by forcing a cork into it underneath, about an inch, so that it do not reach quite to the surface; and having washed off any mud that may be on the surface of the tool with a wet soft piece of sponge, whilst the surface of it is a little moist, place the center of the metal upon the middle of the polisher; then having, with the wet brush, lodged as much water round the edge of the metal as the projecting edge will hold,

hold, fill the hole of the metal and its handle with water, to prevent the evaporation of the moisture, and the consequent adhesion between the speculum and polisher, and let the whole rest in this state two or three hours: this will produce an intimate contact between the two, and by parting, with any degree of warmth they may have acquired by the vicinity of the operator, they will grow perfectly cold together.

By this time you may push out the cork from the polisher, to discharge the water, and give the metal the parabolic figure in the following manner.

Move the metal gently and slowly at first, a very little round the centre of the polisher (indeed after this rest it will move stiffly) then increasing by degrees the diameter of these strokes, and turning the metal frequently round its axis, give it a larger circular motion, and this without any pressure but its own weight, and holding it loosely between the fingers: this manner of working may safely be continued about two minutes, moving yourself as usual round the block, and carrying the round strokes in their increased and largest state, not more than will move the edge of the metal half an inch or five-eighths over the tool. The speculum must not all this while be taken off from the polisher; and consequently no fresh putty can be added.

added. It will not be safe to continue this motion longer than the time above-mentioned; for if the parabolic tendency be carried the least too far, it will be impossible to recover a true figure of that kind but by going through the whole process for the spherical one in the manner before described, by the cross strokes upon the polisher, which takes a great deal of time. However, when there is occasion, it may be done; and I have myself several times recovered the circular figure, when I had inadvertently gone too far with the parabolic; and ultimately finished the metal on the polisher without the use of the hone.

*To try the true figure of the metal.*

It will now be proper to try the figure of the speculum, and that is always best done by placing it in the telescope it is intended for. In order to this, I use the instrument as a kind of microscope, placing the object, however, at such a distance that the rays may be nearly parallel. At about twenty yards a watch-paper, or some such object, on which there are some very fine hair strokes of a graver, is fixed up. The lead must be then taken off from the back of the speculum; which is best done by placing the edge of a knife at the junction of the lead and metal, when, by striking the back of it with a  
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flight blow, the pitch immediately separates, and the handle drops off; the remaining pitch may be scraped off with a knife, taking care that none of the dust stick to the polished face of the metal.

Having placed the speculum in the cell of the tube, and directed the instrument to the object, make an annular kind of diaphragm with card-paper, so as to cover a circular portion of the middle part of the metal between the hole and the circumference, equal in breadth to about an eighth part of the diameter of the speculum: this paper ring should be fixed in the mouth of the telescope, and remain so during the whole experiment, for the part of the metal covered by it is supposed to be perfect, and therefore unemployed.

There must likewise be two other circular pieces of card-paper cut out, of such sizes, that one may cover the center of the metal by completely filling the hole in the last described annular piece; and the other, such a round piece as shall exactly fit into the tube, and so broad as that the inner edge may just touch the outward circumference of the middle annular piece. It would be convenient to have these two last pieces so fixed to an axis that they may be put in their places, or removed from thence so easily as not to displace or shake the instrument,

instrument. All these pieces therefore together will completely shut up the mouth of the telescope.

Let the round piece which covers the center of the metal, or that which has no hole in it, be removed; and, by a nice adjustment of the screw, let the image (which is now formed by the center of the mirror) be made as sharp and distinct as possible. This being done, every thing else remaining at rest, replace the central piece, and remove the outside annular one, by which means the circumference only of the speculum will be exposed, and the image now formed will be from the rays reflected from the outside of the metal. If there be no occasion to move the screw and little metal, and the two images formed by these two portions of the metal be perfectly sharp and equally distinct, the speculum is perfect, and of the true parabolic curve; or at least the errors of the great and little speculum, if there be any, are corrected by each other.

If, on the contrary, under the last circumstance, the image from the outside of the metal should not be distinct, and it should become necessary, in order to make it so, that the little speculum be brought nearer, it is plain that the metal is not yet brought to the parabolic figure; but if, on the other hand, in order to procure distinctness, you be obliged to move the little speculum farther off, then the figure of the great speculum has been carried beyond

the parabolic, and hath assumed an hyperbolic form. When the latter is the case, the circular figure of the metal must be recovered (after having fixed on the handle with soft pitch) by bold cross strokes upon the polisher, finishing it again in the manner above described. If the speculum be not yet brought to the parabolic form, it must cautiously have a few more round strokes upon the polisher; indeed a very few of them in the manner before described make in effect a greater difference in the speculum than would be at first imagined. If a metal of a true spherical figure were to be tried in the above mentioned manner in the telescope (which I have frequently done) the difference of the foci of the two segments of the metal would be so considerable, as to require two or three turns of the screw to adjust them; so very great is the aberration of a spherical figure of the speculum, and so improper to procure that sharpness and precision so necessary to a good reflecting telescope.

This is by no means the case with the object glasses of refractors; for besides that they are in fact never so distinct as well-finished reflectors, the apertures of them are so exceedingly small, compared to the latter, and the number of degrees employed so very small, that the inconvenience of a spherical figure is not so much perceived. Accordingly we observe in the generality of

reflectors (whose specula, unless by accident, are always spherical) that the only true rays which form the distinct image arise from the middle of the metal: and unless the defect be remedied by a considerable aperture, which destroys much light, the false reflection from the inside of the metal produces a greyish kind of haziness, which is never seen in Mr. SHORT'S or indeed in any good telescopes.

Supposing that the two foci of the different parts of the metal perfectly coincide, and that, by the union of them when the apertures are removed, the telescope shews the objects very sharp and distinct, you are not however even then to conclude that the instrument is not capable of farther improvement; for you will perceive a sensible difference in the sharpness of the image, under different positions of the great speculum with respect to the little one, by turning round the great metal in its cell, and opposing different parts of it to different parts of the little metal, correcting by this means the error of one by the other. This attempt should be persevered in for some time, turning round the great speculum about one-sixteenth at a time, and carefully observing the most distinct situation each time the eye-piece is screwed on: when, by trying and turning the great metal all round, the distinctest position is discovered, the upper part of the

metal should be marked with a black stroke, in order that it may always be lodged in the cell in the same position. This is the method Mr. SHORT always used; and the caution is of so much consequence, that he thought it necessary to mention it very particularly in his printed directions for the use of the instrument.

And farther, Mr. SHORT frequently corrected the errors of the great by the little metal in another way. If the great speculum did not answer quite well in the telescope, he cured that defect sometimes by trying the effect of several metals successively, by this means correcting the errors of one by the other; for in several of his telescopes which have passed through my hands, when the sizes and powers have been the same, I have found that the great metals, though very distinct in their proper telescopes, yet have, when taken out and changed from one to the other, spoiled both telescopes, rendering them exceedingly indistinct, which could arise from no other circumstance. For this reason I suppose it was, that he kept, ready finished, a great many large metals of the same focal length, so that, when he wanted to mount a telescope, he might from a great choice, be able to combine those metals which suited each other best. I am strongly inclined to believe this was the case, not only from the above observation, but because  
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he shewed me himself a box of finished metals, in which I am sure there were a dozen and a half of the same focal length.

To return : a little use in working will make the whole of the process of grinding and polishing very easy and certain ; for though I have endeavoured to be as particular as I can (I am almost afraid too much so) it is yet scarcely possible to supply a want of dexterity, arising from habit only, by the most laboured and minute description. And though the above account may appear irksome to the reader, as it lies cold before the eye, I am very sure, whoever attempts to make the instrument, will not complain of it as tediously particular.

I will, however, farther remark, that when the metal begins to move stiffly upon the polisher, and particularly when the figure is almost brought to the parabolic form, it will be necessary to fix the elbows against the sides, in order to give momentum and equability to the motion of the hand by that of the whole body.

The same polisher will serve for several metals, if it be somewhat warmed when you begin to use it.

There is another circumstance, and a material one too, which must not be omitted ; it is this. For the very same reason that the pitch should not be too hard or soft, the work will not proceed well in the heat of summer,

or the cold of winter: in the latter, it may be possible to remedy the defect by having the room warmed with a stove; and in the summer, the other inconvenience may perhaps be avoided by using a harder kind of pitch; but I much doubt in either case whether the work will go on so kindly: I have myself always wrought in spring and autumn.

The process of polishing, and indeed grinding upon the hones, will not go on so well if it be not continued uninterruptedly from beginning to end; for if the work of either kind be left but for a quarter of an hour, and you then return to it again, it will be some time before the tool and metal can get into a kindly way of working; and till they do, you are hurting what was done before.

I have all along supposed that the metal we have been working was about four inches diameter: if it be either larger or smaller, the sizes of the hones, bruiser, and polisher, must be proportionably different. I never find any ill consequence arising from the different expansion from heat and cold in any of the tools, though they be made of different metals and substances, unless the inconvenience, occasioned by the interruption before hinted at, be thought to result from thence; for the alteration produced in the surface of the speculum, both by grinding and polishing, is so much quicker than any that can be supposed to arise from

from the former cause, that it is never attended with any practical consequence.

Magnifying very minute objects, and particularly reading at a distance, have been generally considered as the surest tests of the goodness of a telescope; and indeed when the page is placed at a great distance, so that the letters subtend but a very small angle at the eye, if then they appear with great precision and sharpness, it is most probable that the instrument is a good one. But we are, nevertheless, sometimes apt to be deceived by this method; nor is it always possible to determine upon the different merits of two instruments of equal power, by this mode of examination; for when the letters are removed to the utmost extent of the powers of the two instruments, the eye is apt to be prejudiced by the imagination. If two or three words can be here and there made out, all the rest are guessed at by the sense; inasmuch that an observer, zealous for the honour of his instrument, is very apt to deceive himself in spite of his intentions. The surer test is by figures, where you can procure no aid from this sort of deception. In order to examine my reflecting telescopes, I made upon a piece of copper and on a black ground, six lines consisting of about twelve pieces of gold figures, and each line of figures differing in magnitude, from the smallest that could be distinctly made to those  
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of about two-tenths of an inch long; moreover, the figures in the several lines were differently disposed, and the sum of each line also differed. It is evident that by this method all guess is precluded; and that of two instruments, of the same powers, that which can make out the least order of figures, which will be known by the sum, is the best telescope. Such a plate I caused to be fixed up for experiments against the top of a steeple, about three hundred yards North of my house; and it will serve to give some idea of the distinctness with which very small figures could be made out at that distance, by saying, that in a clear state of the air, and with the Sun behind me, with a telescope of eighteen inches focal length, which Count BRUHL did me the honour to accept and now has in his possession, I have seen the legs of a small fly, and the shadows of them, with great precision and exactness.

I cannot conclude without indulging myself in an observation on the amazing sagacity of Sir ISAAC NEWTON in every subject upon which he thought fit to employ his attention. It was he who first proposed, and indeed practised, the polishing with pitch; a substance which at first sight perhaps every one but himself would have thought very improper, from its softness, to produce that correctness of figure so necessary upon these occasions; and yet I do believe, that it is the only substance in nature

that is perfectly well calculated for the purpose; for at the same time that it is soft enough to suffer the putty to lodge very freely on its surface, and for that reason to give a most tender and delicate polish; it is likewise totally inelastic, and therefore never, from that principle, suffers any alteration in the figure you give it. If the first makers of the instrument, therefore, had given proper credit to, or had simply followed the hint Sir ISAAC gave, it would have saved them infinite trouble, and they would have produced much better instruments; but the pretended refinement, of drawing a tincture from pitch with spirits of wine, affords you only the resinous, hard, and untractable part of the pitch, divested of all that part of its original substance which is necessary to give it that accommodating pliability in which its excellence consists.

It is needless to swell this account with a detail of the process for polishing the little speculum, as it must be conducted in the same manner which has been already described in that of the large one; only observing, that as the little metal has an uninterrupted face, without a hole, so there is no occasion for one in the polisher; and likewise that, as a spherical figure is all that need here be practically attempted, so the difficulty in finishing is infinitely short of that of the other.

As it is always necessary to folder to the back of the little speculum a piece of brass, as a fixture for the screw to adjust its axis, I shall just hint a safe and neat method of doing it, which may be very useful to the optical or mathematical instrument-maker upon other occasions. Having cleaned the parts to be foldered very well, cut out a piece of tin-foil the exact size of them; then dip a feather into a pretty strong solution of *sal ammoniac* in water, and rub it over the surfaces to be foldered; after which place the tin-foil between them as fast as you can (for the air will quickly corrode their surfaces so as to prevent the folder taking) and give the whole a gradual and sufficient heat to melt the tin. If the joints to be foldered have been made very flat, they will not be thicker than a hair: though the surfaces be ever so extensive, the foldering may be conducted in the same manner, only that care must be taken, by general pressure, to keep them close together. In this manner, for instance, a silver graduated plate may be foldered on to the brass limb of a quadrant, so as not to be discernable by any thing but the different colour of the metals. This method was communicated to me by the late Mr. JACKSON, who during his life kept it a secret, as he used it in the construction of his quadrants, and is, I believe, not as yet known to any workman.

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In the annexed plate are figured the shape of the leaden tool for rough-grinding; the hones; and the apparatus to be applied to the mouth of the telescope, to ascertain the true figure of the speculum.

P O S T S C R I P T.

It was some time after I had written the above account that I saw Mr. SHORT's method of polishing object glasses for refracting telescopes, which is published in the Transactions. By that paper I find that what I before strongly suspected is really the case, *viz.* that he knew how well pitch was calculated for purposes of this kind. Only it may be remarked, that as glass is much harder, polishes much slower, and consequently does not wear away and alter its figure so soon as the metal of which the speculum is made; and as at the same time (on account of the very small apertures allowed to telescopes of this sort) nothing more than a spherical figure is proposed; he is therefore obliged to use pitch in a hard, friable, and stubborn state: whereas, considering the delicate substance of the metal speculum, and the figure intended to be given to it, the soft pitch of the common sort, by suffering the putty to bed itself in its substance,

produces the most beautiful polish; and by its pliability is better calculated for that mutual accommodation between polisher and metal, so necessary to the figure proposed.

#### EXPLANATION OF THE FIGURES.

Fig. 1. The grinder for working off the rough face of the metal; the black strokes represent deep grooves made with a graver.

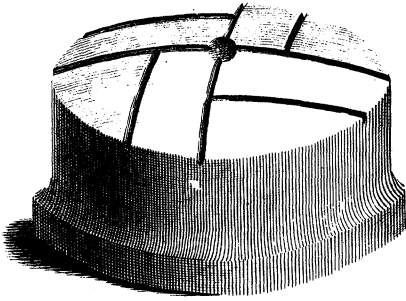
Fig. 2. The bed of hones, which is to complete the spherical figure of the speculum, and to render its surface fit for the polisher.

Fig. 3. An apparatus for examining the parabolic figure of the speculum.

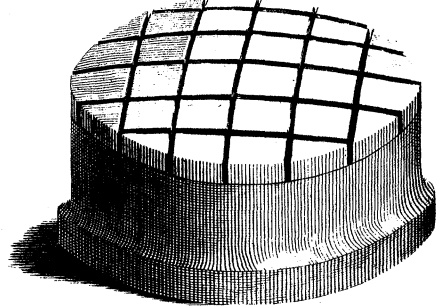
AA The mouth of the telescope, or edge of the great tube.

BB A thin piece of wood fastened into, and flush with the end of the tube; to which is permanently fixed the annular piece of paste-board cc, intended to cover, and to prevent the action of the corresponding part of the speculum.

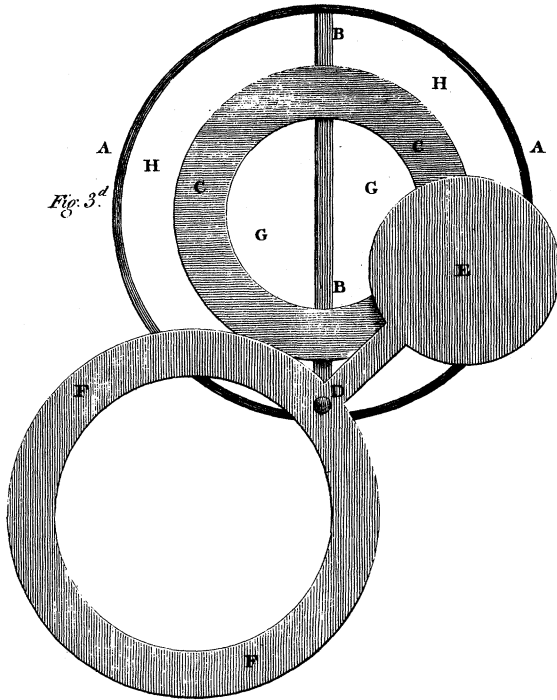
*Fig. 1.<sup>d</sup>*



*Fig. 2.<sup>d</sup>*



*Fig. 3.<sup>d</sup>*



**D** Another piece of paste-board, fixed by a pin to the piece of wood **BB**, on which it turns as on a center; so that the great annular opening **HH** may be shut up by the ring **FF**, or the aperture **GG** by the imperforate piece **E** in such manner that, in the first instance, the reflexion may be from the center, and in the latter from the circumference, of the great speculum.

